NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4172

NOISE SURVEY UNDER STATIC CONDITIONS OF A TURBINE-DRIVEN FULL-SCALE MODIFIED SUPERSONIC PROPELLER WITH AN ADVANCE RATIO OF 3.2

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SUMMARY

Overall sound-pressure levels and frequency spectra have been obtained under static conditions from a modified supersonic propeller designed to operate efficiently at a high forward speed without the high noise levels associated with the supersonic propeller. The three-blade, 10-foot-diameter, 1,700-rpm propeller is powered by a turbine engine and is designed to operate at a Mach number of 0.95 at 40,000 feet.

The results consist of overall sound-pressure levels and frequency spectra obtained from analyses made of recordings taken during ground runups of the modified supersonic propeller. These results are compared with similar results obtained with a conventional subsonic propeller reported in NACA Technical Note 3422 and with a supersonic propeller reported in NACA Technical Note 4059.

The noise output of the modified supersonic propeller displays approximately the same overall sound-pressure level and frequency-spectrum characteristics, under static conditions, as the current subsonic transport propeller reported in NACA Technical Note 3422. The maximum overall sound-pressure level produced was 120 decibels at a distance of 100 feet. This overall noise output represents a lowering of the maximum overall sound-pressure levels by approximately 10 decibels at comparable engine horsepowers as compared with the output of the supersonic propeller reported in NACA Technical Note 4059. In general, it may be stated that a propeller may be designed to possess good aerodynamic performance at high forward speeds and still provide, under static conditions, an overall noise output not greater than that of propellers currently being used on transport airplanes, and with a similar frequency spectrum.

INTRODUCTION

Airplane propellers are known to possess good efficiencies at high forward Mach numbers. Optimum efficiency is obtained by operating thin blade sections at supersonic resultant speed. The supersonic speed is necessary in order to maintain an optimum advance angle (approximately 45°) of the propeller that will result in maximum profile efficiency for the chosen thickness-ratio distribution. A propeller design of this type is referred to as a supersonic propeller. Such a propeller, however, produces static and take-off noise levels that exceed current transport noise levels because of the high rotational tip speeds. These noise levels may be reduced only by reducing the rotational tip speed of the propeller.

A relatively high efficiency under design conditions may still be obtained by relaxing the requirement of optimum advance angle while maintaining the thin blade sections. Operation at an advance angle higher than optimum results in a lower tip rotational speed and a quieter propeller. The present investigation has been conducted on such a modified supersonic propeller.

Thus far, research has been conducted on two other propellers with the same propeller research airplane used in the investigations of references 1 and 2. A propeller of conventional design typical of the propellers operating in transport service today is discussed in reference 1. A propeller, utilizing the supersonic design procedure, is discussed in reference 2. The modified supersonic propeller of the present investigation has identical geometrical characteristics to the supersonic propeller of reference 2, the only difference being a different pitch distribution that is the result of the difference in design advance ratios. The design forward Mach number of both propellers is 0.95 at 40,000 feet. The rotational tip speed under static conditions is a Mach number of 1.2 for the supersonic propeller as compared with a tip Mach number of 0.8 for the propeller of reference 1 and the present investigation.

Because of the relationship of the three propeller designs, the results of the present investigation are compared with some of the results of references 1 and 2.

SYMBOLS

B number of blades

b blade width (chord), ft

D	propeller diameter, ft
h	blade-section maximum thickness, ft
R	propeller tip radius, ft
r	radius to blade element, ft
β	blade angle, deg
P	power absorbed by propeller, hp
M_t	propeller tip Mach number
T	thrust of propeller, lb
M_d	design forward Mach number
J	design advance ratio, V/nD
V	forward velocity, ft/min
n	propeller speed, rpm
σ	solidity, $Bb/2\pi r$

APPARATUS AND PROCEDURE

The modified supersonic propeller used in the present investigation is a three-blade configuration with a 10-foot diameter and an advance ratio of 3.2. The blades are constructed of solid SAE 4340 steel having an ultimate tensile strength of 180,000 pounds per square inch. A photograph of the propeller mounted on the test airplane is shown in figure 1. The blade-form curves and pertinent dimension ratios are given in figure 2. Significant parameters of the modified supersonic propeller and the propellers of references 1 and 2 are given in table I. A complete description of the airplane, turbine engine, and instruments used to obtain propeller rotational speed and engine horsepower is contained in references 1 and 2. Thrust values were obtained from measured values of the blade angle and from a static calibration of blade angle plotted against thrust obtained from dynamometer tests. The power input to the modified supersonic propeller was limited to 1,050 horsepower because of the three-blade configuration and the proximity of the known stall flutter boundary of this propeller under static conditions.

Block diagrams of the noise recording and analyzing equipment used during the investigation are shown in figure 3; the equipment varied from that used in references 1 and 2 in that an Altec-Lansing model M-14 microphone system incorporating a 21BR150 microphone was used.

Sound recordings were taken at various azimuth-angle stations, on the ground, around a circle with a 100-foot radius about the propeller hub. The location selected for the sound measurements was a concrete apron with no buildings or other large reflective surfaces within 300 yards.

The radial distribution was made during one continuous engine test, in which the power setting was 1,050 hp and the propeller speed was 1,675 rpm. The engine operating conditions were varied during the investigation to enable sound recordings to be made at station 105° to show the effects of propeller rotational speed and power. The test conditions and results of the noise analysis are presented in table II.

The calibration of the noise recording and analyzing equipment was performed essentially in the same manner as that described in reference 1. Other pertinent information is as follows:

Clearance of ground by propeller, ft	1.0
Wind from 0° to nose, knots	4
Temperature, °F	65
Barometric pressure, in. Hg	30.1

RESULTS AND DISCUSSION

The modified supersonic propeller used in the present investigation is one of a series of propeller designs to be tested in the propeller flight research program of the National Advisory Committee for Aeronautics. Thus far, three propeller designs have undergone noise investigations. The relation of these three propellers makes it desirable to present some of the results of the first two propeller designs investigated (refs. 1 and 2) and to compare these results with those of the present investigation. The propeller of reference 1 is a conventional type and differs mainly from the present modified supersonic propeller in that the blades have higher thickness ratios and it is a four-blade configuration. The propeller of reference 2 is a supersonic propeller with the same design conditions of the present propeller except for a lower advance ratio. The measurements of references 1 and 2 have been adjusted for differences in power and distance to agree with the measurements of the present investigation.

Distribution of Overall Sound-Pressure Levels

The radial distributions of the overall sound-pressure levels of the three propellers are shown in figure 4. The maximum overall sound-pressure level for the modified supersonic propeller is seen to be 120 decibels in the right rear quadrant of the propeller plane. This value is approximately 10 decibels lower than the maximum overall noise level produced by the supersonic propeller. Also, a slight shift in the orientation of the maximum level station is noted.

The comparison shows that the modified supersonic propeller produces noise levels only a few decibels higher than those of the subsonic propeller; however, several propeller parameters differ in the comparison. The first parameter, the number of blades, is probably the cause of the lower measured sound-pressure levels of the subsonic propeller. The second parameter, the thickness of the propeller blades, is not expected to influence the noise output under static conditions. At flight speeds, however, noise due to thickness may increase to an appreciable extent as is suggested by the theory of reference 3 and by the results of the tests conducted in reference 4.

The agreement of the overall sound-pressure levels of the modified supersonic propeller with those of the subsonic propeller and the agreement shown in reference 1 between the calculated overall levels by the theory of reference 5 and the measured levels of the subsonic propeller implies that the theory will also apply equally well for the present modified supersonic propeller. A complete comparison of the theory and test results of the subsonic propeller is made in reference 1.

The modified supersonic propeller shows an unsymmetrical distribution of overall noise similar to that of the subsonic propeller, the highest level (120 decibels) being in the right rear quadrant. The supersonic propeller displayed an unsymmetrical distribution but to a lesser degree. As mentioned in reference 2, the difference in distribution is believed to be due in part to the differences in ground clearances affecting the inflow to the propellers.

Variation of Sound-Pressure Level With Frequency

The frequency spectrum of each of the three propellers is plotted in figure 5 for station 105°. The spectrum of the modified-supersonic propeller is seen to be very near the same as that of the subsonic propeller with a rapid dropoff in sound-pressure level at the higher harmonics. The supersonic propeller displays high noise levels in the higher harmonics which are usually displayed by a high-tip-speed propeller. At this station the supersonic propeller produces 9 decibels higher overall sound-pressure level than does the modified supersonic propeller.

Effect of Power Variation

The overall sound-pressure levels and the frequency spectra of the noise measured at station 105° are shown in figure 6 for power settings of 150, 350, and 1,050 horsepower. Propeller rotational speed was maintained at 1,675 rpm for the three power settings.

Briefly, the effect of power increases at the maximum sound-level station (station 105°) is seen generally to raise the entire spectrum of the modified supersonic propeller. The supersonic propeller of reference 2 shows that power increases raise only the lower harmonic content of the spectra. The variation of engine power produced less variation in sound-pressure levels than the calculation by the theory of reference 5 indicated.

Effect of Propeller-Rotational-Speed Reduction

During taxiing operations, which require low engine powers, a reduction in noise may be afforded by operating the propeller at a reduced speed. A propeller-rotational-speed reduction on the engine used in the present test requires the same percentage of reduction in engine speed. This reduction penalizes the power output and efficiency to an extent intolerable except for taxi purposes. Other engines are available (free-turbine engines) that allow large reductions in propeller rotational speed to be achieved at a small penalty.

In order to show the effect of reducing propeller speed on the overall sound-pressure levels and the frequency spectra, measurements were made at station 105° at rotational speeds of both 1,675 rpm ($M_t = 0.78$) and 1,370 rpm ($M_t = 0.64$). These measurements are shown in figure 7.

For the low power inputs used, the overall level is reduced by only 4 decibels. However, the spectra show that the reduction in noise is greatest in the higher frequencies. A reduction in this range of the spectra would be most profitable from considerations of the comfort of the passengers and the neighborhood of the airport.

CONCLUDING REMARKS

The results consisted of overall sound-pressure levels and frequency spectra obtained from an analysis made of recordings taken during ground runups of the modified supersonic propeller. These results are compared with similar results obtained with a conventional subsonic propeller reported in NACA Technical Note 3422 and with a supersonic propeller reported in NACA Technical Note 4059.

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In general, it may be stated that a propeller may be designed to operate at high forward speeds and still produce, under static conditions, an overall noise output not greater than that of propellers currently being used on transport airplanes, and with a similar frequency spectrum.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 30, 1957.

REFERENCES

1. Kurbjun, Max C.: Noise Survey of a 10-Foot Four-Blade Turbine-Driven Propeller Under Static Conditions. NACA TN 3422, 1955.

2. Kurbjun, Max C.: Noise Survey of a Full-Scale Supersonic Turbine-Driven Propeller Under Static Conditions. NACA TN 4059, 1957.

3. Arnoldi, Robert A.: Near-Field Computations of Propeller Blade Thickness Noise. Rep. R-0896-2, United Aircraft Corp. Res. Dept., Aug. 30, 1956.

4. Kurbjun, Max C.: Effects of Blade Plan Form on Free-Space Oscillating Pressures Near Propellers at Flight Mach Numbers to 0.72. NACA TN 4068, 1957.

5. Hubbard, Harvey H.: Propeller-Noise Charts for Transport Airplanes. NACA TN 2968, 1953.

TABLE I

PARAMETERS OF THE THREE PROPELLERS

Source of data	Type of propeller	Design forward Mach number	Altitude, ft	J	β, deg	$\sigma_{0.7R}$	$(h/b)_{tip}$	$(h/b)_{spinner}$	M_t
Present report	Modified supersonic	0.95	40,000	3.2	3	0.154	0.2	0.8	0.8
Reference 2	Supersonic	.95	40,000	2.2	3	.154	.2	.8	1.2
Reference 1	Conventional transport (subsonic)	.60	20,000	3.2	4	.182	.5	.11	.8

TABLE II

TEST CONDITIONS AND RESULTS OF NOISE ANALYSIS FOR A MODIFIED SUPERSONIC PROPELLER

[On ground; 100-ft-radius circle]

Test conditions					Sound-pressure level, db (reference pressure level, 0.0002 dyne/cm^2)									Remarks
Station, deg	T, lb	P, hp	Blade angle, deg	Fundamental blade passage frequency, cps	Overall	Order of harmonic								
						1st	2d	3d	4th	5th	6th	7th	8th	
0	2,540	1,050	16	83.5	108.0	102.5	100.0	99.5	97.5	99.5	95.0	93.5	93.0	Polar distribution: constant power condition, continuous run, 1,675 rpm, $M_t = 0.78$, right microphone
30	2,540	1,050	16	83.5	107.5	102.5	99.5	97.5	95.5	96.0	95.0	95.5	92.0	
60	2,540	1,050	16	83.5	108.5	102.5	102.5	101.0	98.5	92.5	96.0	95.5	93.0	
90	2,540	1,050	16	83.5	119.5	114.5	115.0	106.5	109.0	100.5	96.5	93.0	91.0	
105	2,540	1,050	16	83.5	120.0	117.0	115.5	104.5	110.0	102.5	95.5	98.5	94.5	
120	2,540	1,050	16	83.5	120.0	119.5	113.0	110.5	104.5	105.5	91.0	102.5	100.0	
240	2,540	1,050	16	83.5	115.0	109.0	96.5	100.5	100.5	107.5	107.0	103.0	97.0	Polar distribution: constant power condition, continuous run, 1,675 rpm, $M_t = 0.78$, left microphone
255	2,540	1,050	16	83.5	115.0	113.0	106.5	105.0	99.5	97.0	95.0	95.0	96.0	
270	2,540	1,050	16	83.5	114.5	112.0	108.0	102.5	102.5	98.0	90.0	93.5	91.0	
300	2,540	1,050	16	83.5	108.0	104.0	101.0	95.5	96.5	98.0	88.5	89.5	93.0	
330	2,540	1,050	16	83.5	105.0	102.0	96.5	92.0	92.0	94.5	84.5	86.5	90.0	
360	2,540	1,050	16	83.5	108.5	104.5	93.5	92.5	94.5	96.0	88.0	92.5	88.5	
105	670	150	5	83.5	110.0	106.0	103.5	103.5	99.0	97.5	94.0	89.0	89.0	Variation of power: 1,675 rpm, $M_t = 0.78$
255	670	150	5	83.5	106.5	101.5	102.5	97.0	96.5	93.0	91.0	93.0	88.0	
105	1,350	350	10	83.5	114.0	110.0	109.0	107.0	102.5	98.5	95.5	94.5	90.0	
255	1,350	350	10	83.5	110.0	105.0	106.0	99.0	100.0	96.0	93.0	96.0	92.0	
105	2,540	1,050	16	83.5	120.0	117.0	115.5	104.5	110.0	102.5	95.5	98.5	94.5	
255	2,540	1,050	16	83.5	114.5	113.0	106.5	105.0	99.5	97.0	95.0	95.0	96.0	
105	450	100	5	68.2	106.0	103.5	101.5	93.5	89.5	86.0	85.5	84.5	83.0	Variation of power: 1,370 rpm, $M_t = 0.64$
255	450	100	5	68.2	102.0	101.0	87.5	90.5	86.0	84.5	79.5	82.0	80.5	
105	860	190	10	68.2	106.5	103.0	102.0	94.5	87.0	88.5	89.0	89.0	84.5	
255	860	190	10	68.2	106.0	103.5	91.0	90.5	95.0	93.5	95.5	93.5	92.0	

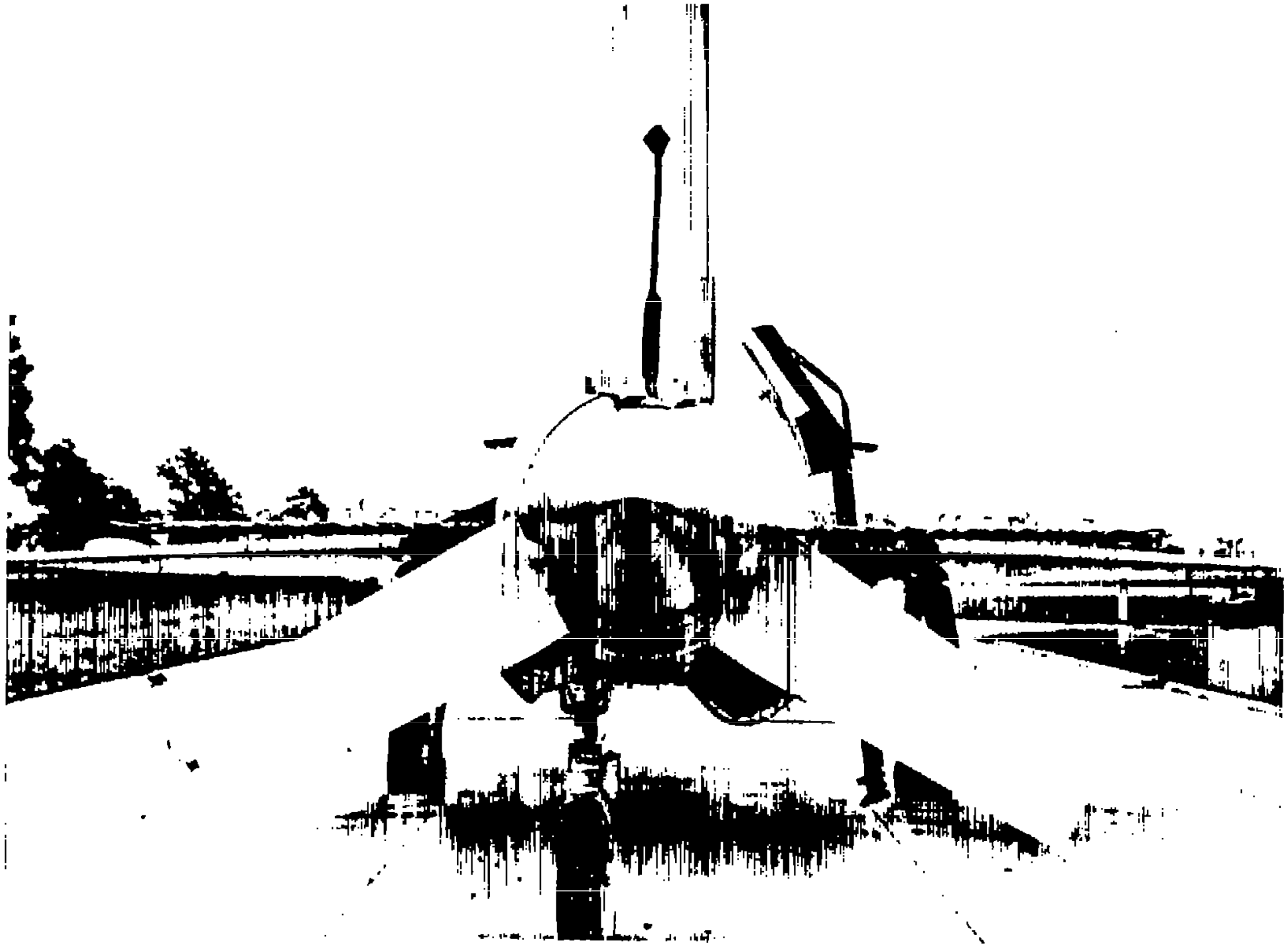

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Figure 1.- Modified supersonic propeller mounted on test airplane.

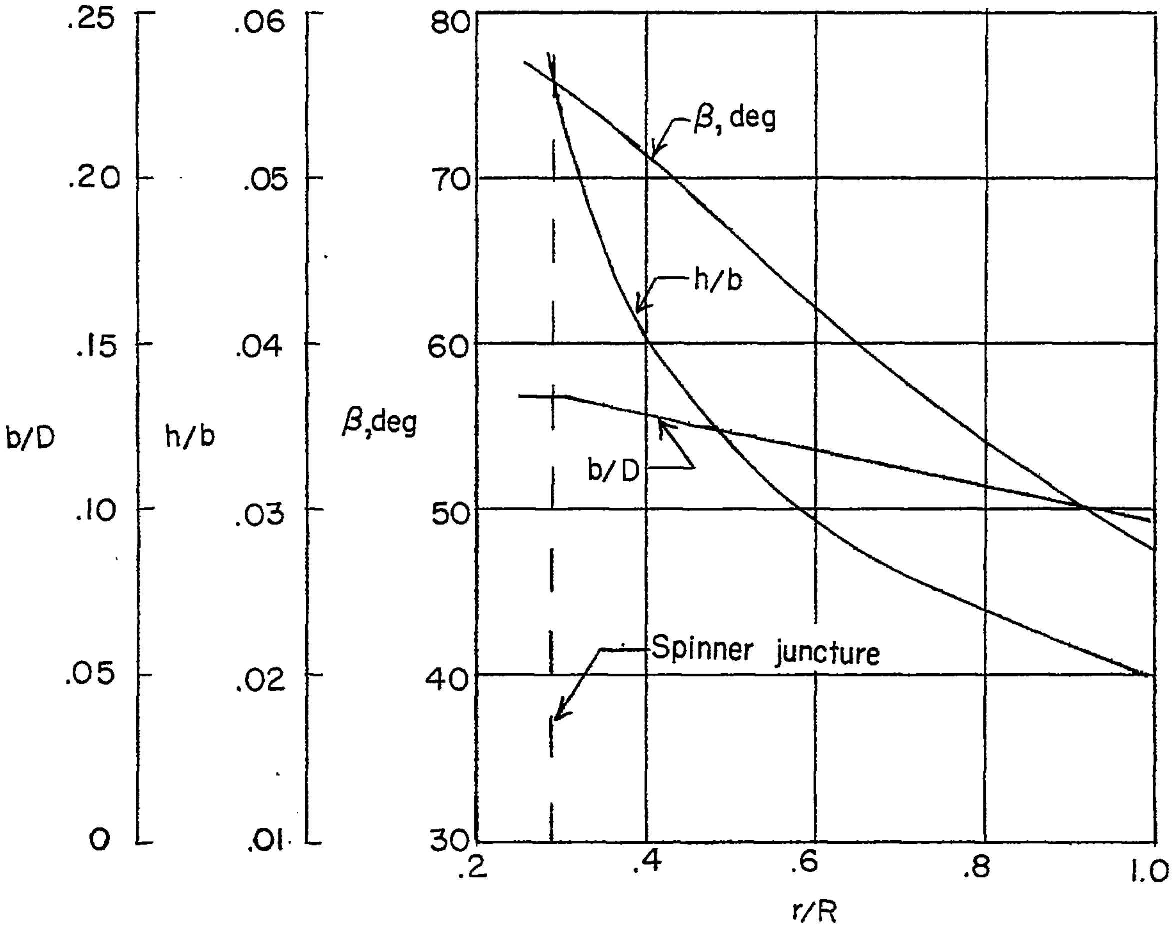
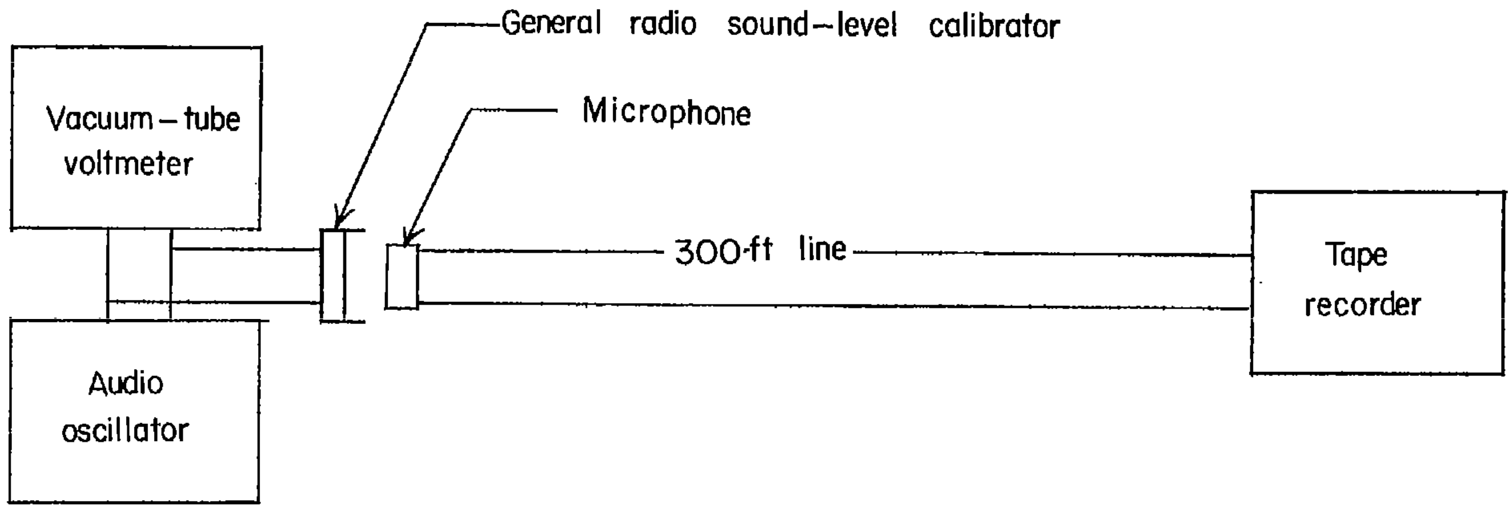
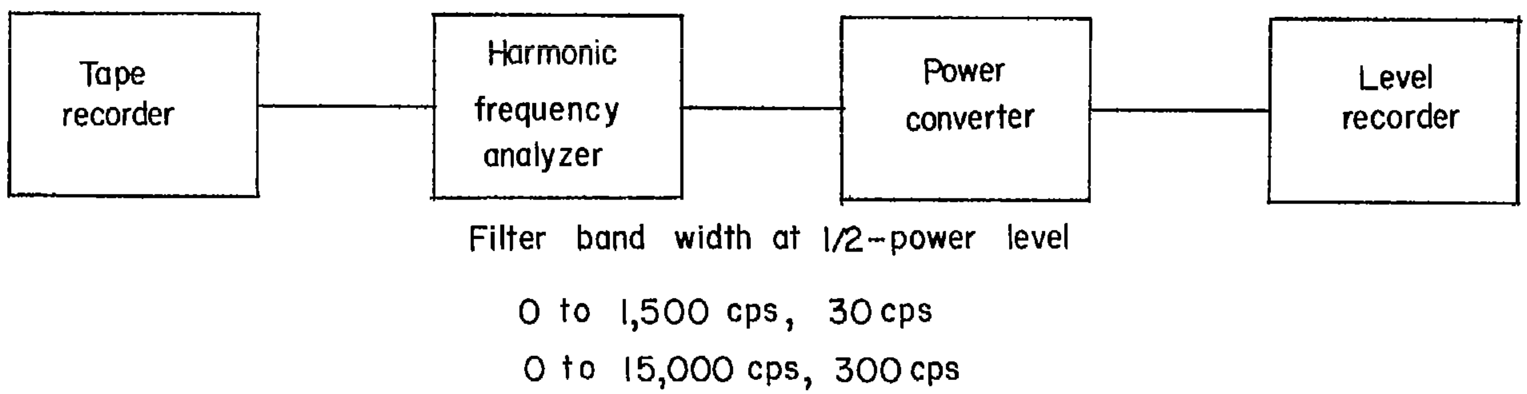


Figure 2.- Blade-form curves of modified supersonic propeller used in present investigation.



(a) Sound recording and calibrating equipment.



(b) Sound analyzing equipment.

Figure 3.- Block diagrams of recording and analyzing equipment used in investigation.

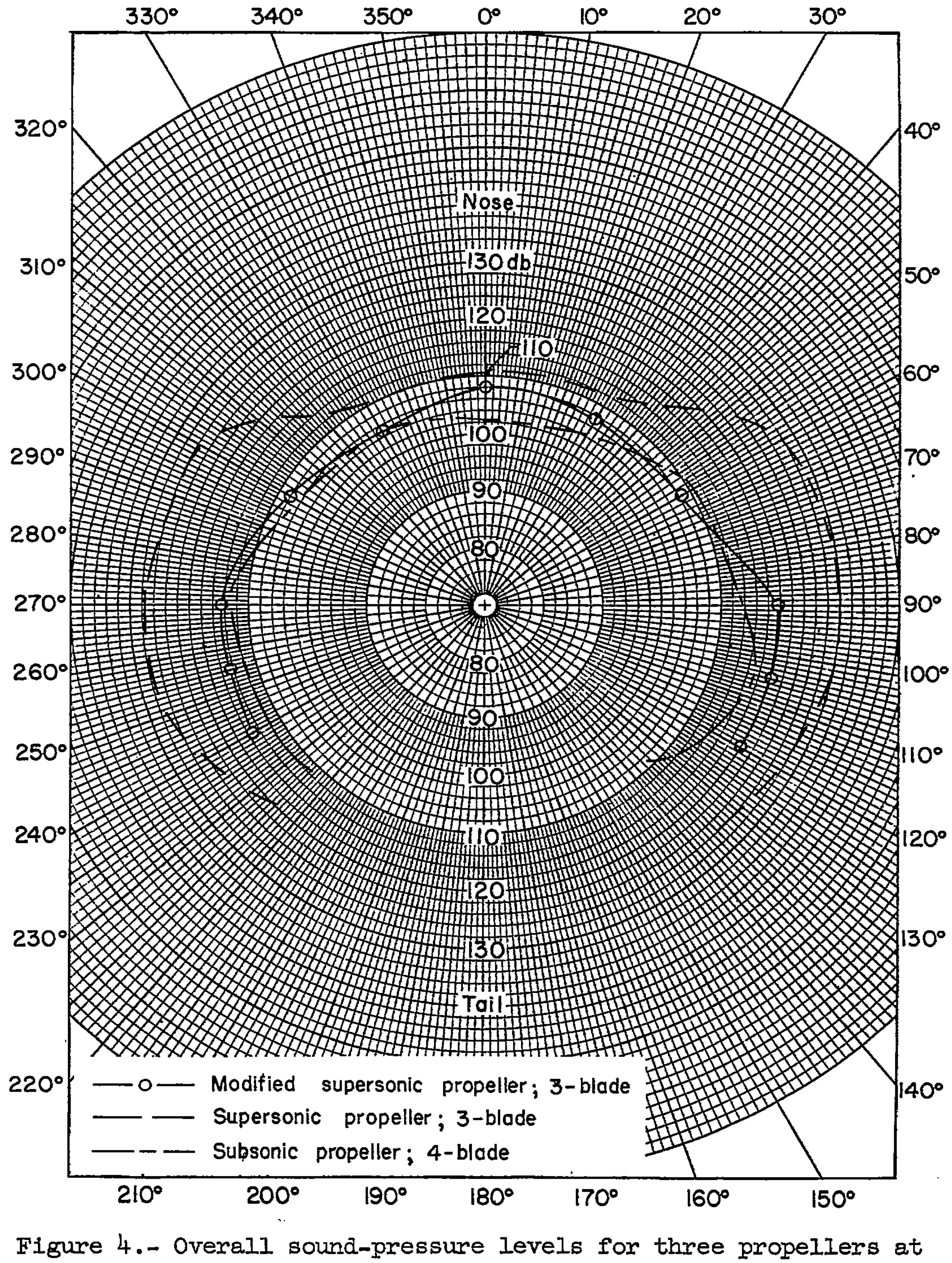


Figure 4.- Overall sound-pressure levels for three propellers at 100-foot distance. P = 1,050 hp.

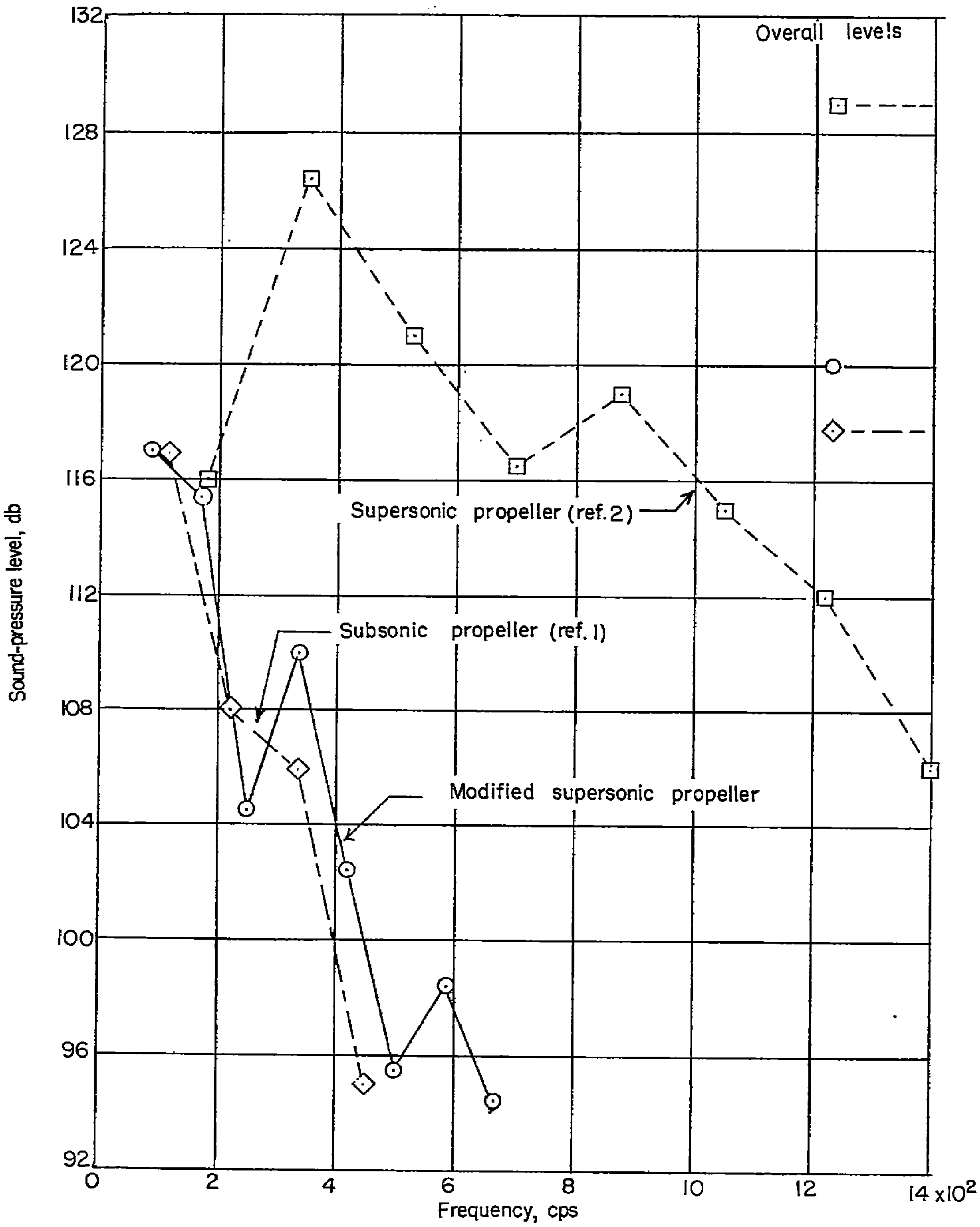


Figure 5.- Comparison of overall sound-pressure levels and frequency spectra of three propellers. Station 105°; 100-foot distance; P = 1,050 hp.

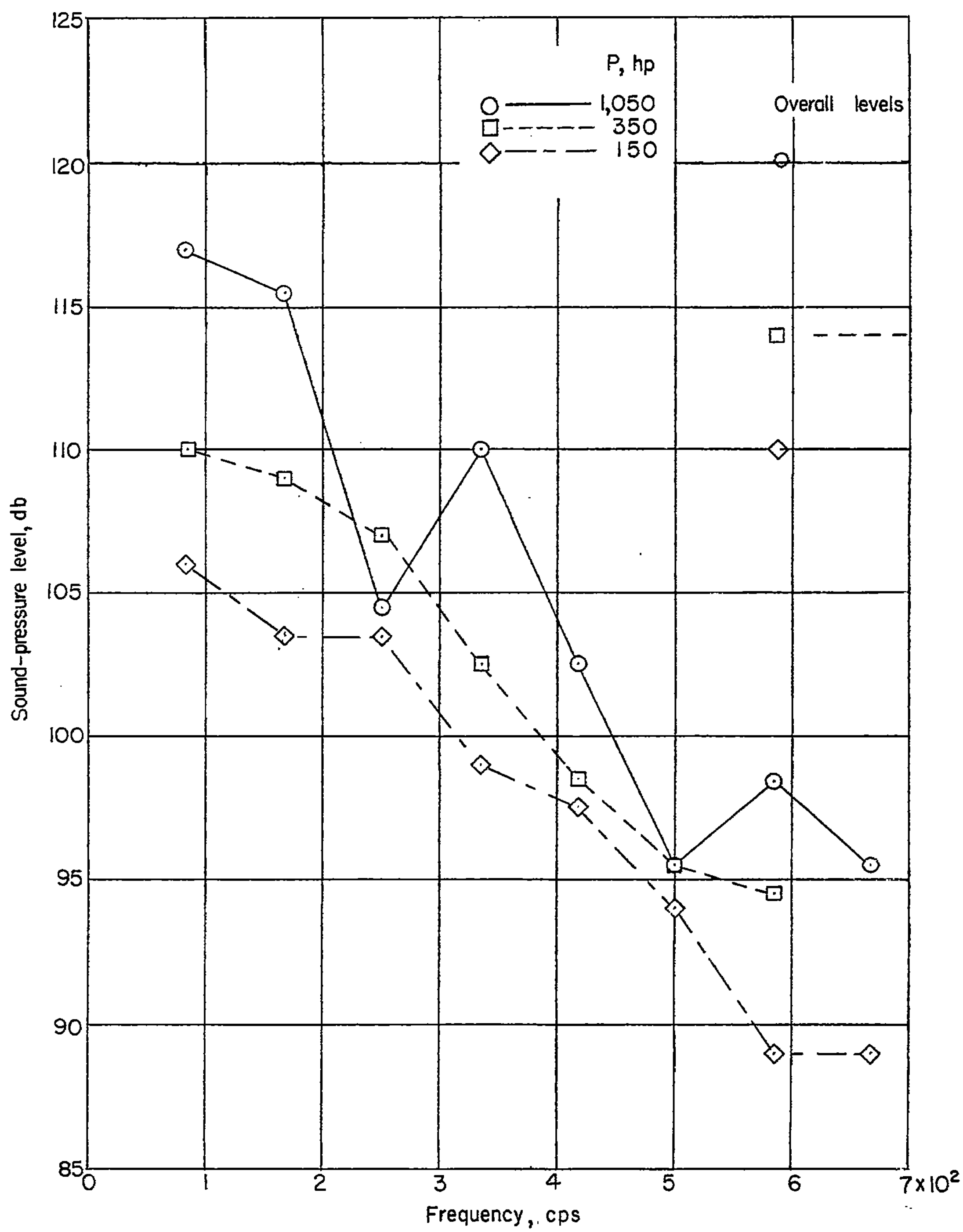


Figure 6.- Comparison of overall sound-pressure levels and frequency spectra for modified supersonic propeller at several power settings. Station 105°; 100-foot distance.

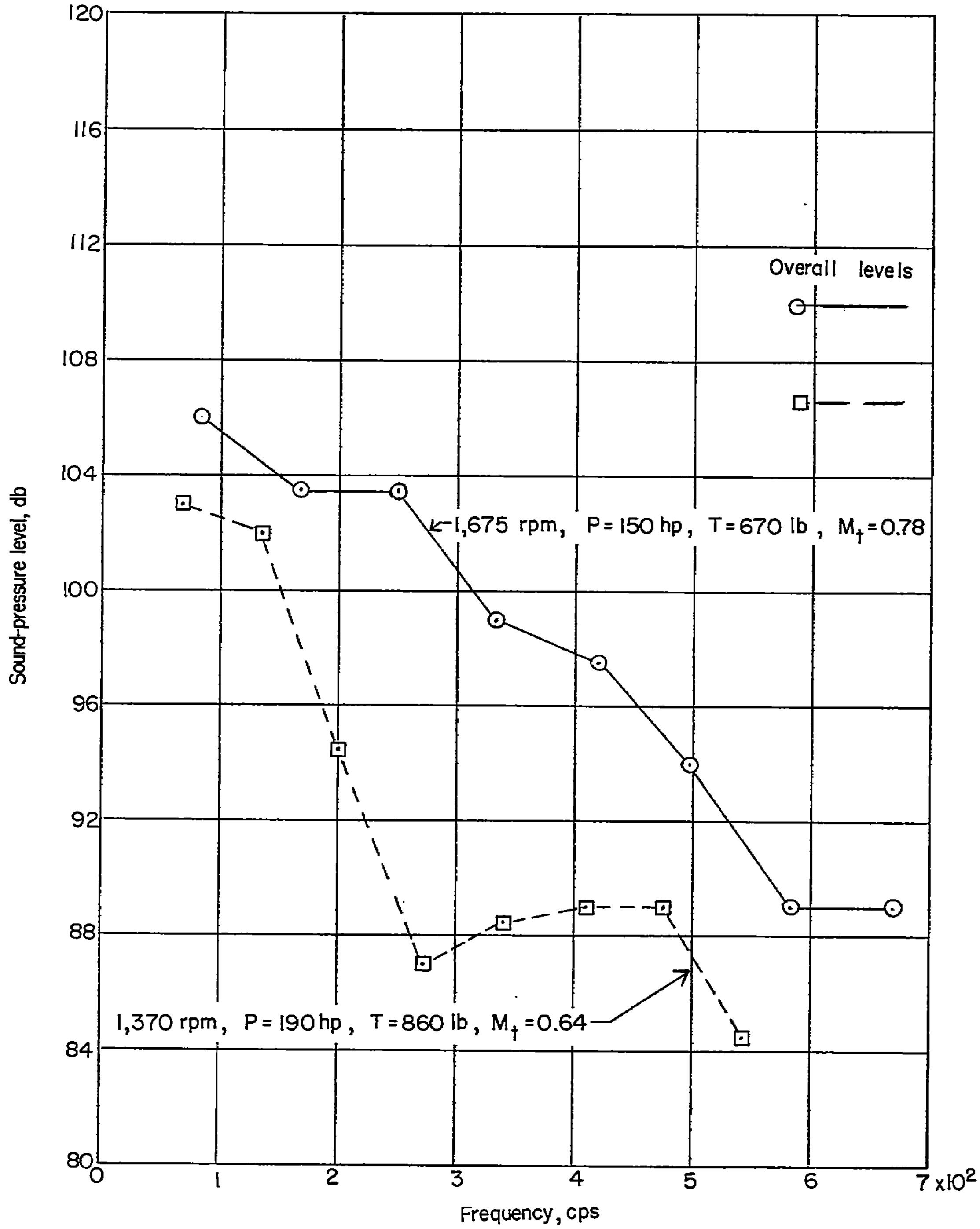


Figure 7.- Comparison of overall sound-pressure levels and frequency spectra of modified supersonic propeller at two rotational speeds. Station 105°; 100-foot distance.